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The Single Strip Tester of Magnetic Materials with AMR Sensors Array

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Abstract ***– The new design of Single Strip Tester device is proposed. The traditionally used coil sensors (tangential coil or Rogowski coil) are substituted by the array of magnetoresistive sensors. Such solution enables to simplify the tester (lack of integrating circuits or compensation feedback). When the sensors are connected in series the output signal is significantly lareg (about 500 mV/(kA/m). When the sensors are multiplexed the analysis of homogeneity and grain structure is possible.***

Keywords**: *electrical steel tester, AMR magnetic sensors, magnetic materials evaluation***

1. INTRODUCTION

Electrical steel is commonly tested using the Epstein frame or SST (Single Sheet Tester) device. The main advantage of these testing methods is that they are standardized [1,2]. But one of the drawbacks of these methods is large value of wasted material (although large sample – 50 cm × 50 cm in case of SST – is sometimes assumed as advantageous, because this way we can average the tested result for the large sample, often heterogeneous).

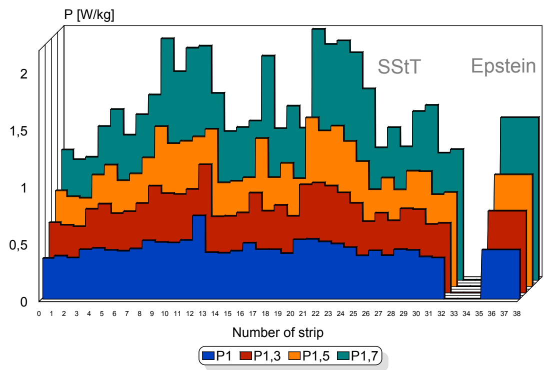

Fig.1. Comparison of the tested results of 32 strips investigated individually by SStT device and by Epstein method

Authors proved [3] that the SST device can be with success substituted by SStT (Single Strip Tester) device. Fig.1 presents the results of testing of 32 strips by single strip tester and the result of testing of the same set of strips in form of Epstein frame. Average value obtained from 32 results was practically the same as in the case of Epstein result (with difference not larger than several percent). But at the same time it was possible to obtain information about material heterogeneity which is lost in the case of Epstein or SST method (Figure 1 presents the case of extremely large heterogeneity of magnetic material).

Thus we can conclude that measurements performed by SStT device is much better than Epstein or SST because we obtain much more information about quality of tested steel.

II. TYPICAL DESIGN OF SINGLE STRIP TESTERS

There are two main methods of measurement of magnetic field strength in strip sample [4]. The most popular is to make use of Ampers' law and to determine the *H* value from the magnetizing current value *I*

$$H = \frac{n}{l} I \qquad (1)$$

But to correct estimation of *H* value it is necessary to know the number of turn *n* and the length of magnetic path *l*. In the case of closed magnetic circle (Epstein case) it is relative easy to determine the magnetic path length (although also in the case of Epstein frame the length $l = 0.94\ m$ is only assumed, not determined). In the case of open sample circuit, as SStT device we practically do not know the length of magnetic path.

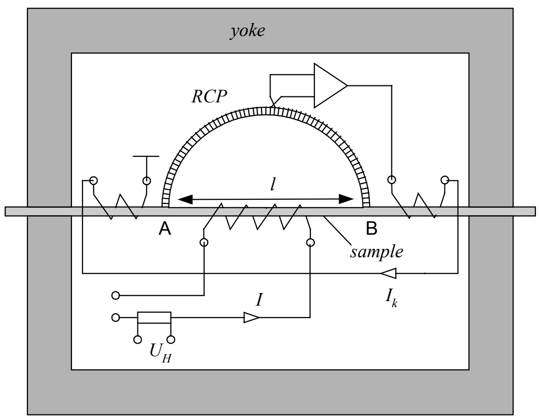

Fig.2. The application of Rogowski/Chattock Potentiometers (RCP) in compensation method of *H* measurement

A smart method of solving of this problem proposed team from Wolfson Centre of Magnetics Technology [5]. The old principle of Iliovici permeameter and Chattoc/Rogowski Potentiometer RCP have been applied (Fig.2). Due to feedback current I_k the magnetic fields in the yoke and in air gaps are compensated and it can be assumed that the effective magnetic path is equal to the distance A – B (ends of the RCP). Because the length l is known the current I can be used for magnetic field strength determination.

The testing device presented in Fig.2 is rather complex. Moreover the application of Amper's law to the determination of magnetic field strength is questioned and direct measurement of magnetic field by magnetic field sensor is recommended [6]. Indeed if the tangential magnetic field sensor is placed directly above the sample the detected magnetic field is equal to the field in the sample. Such method of magnetic field determination is preferred by Japan teams [7] and as the sensor flat coil (H-coil) is used.

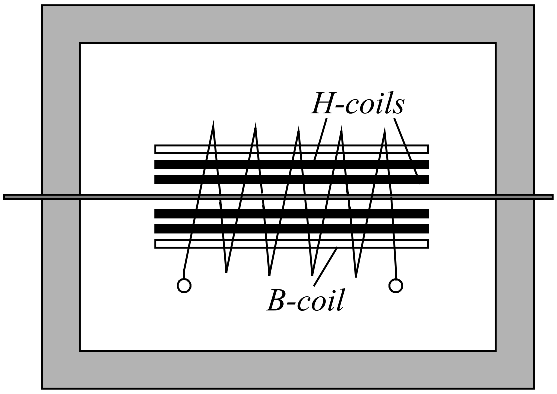

Fig. 3. The SStT device with two H-coils for magnetic field strength measurement

Fig. 3 presents the coils arrangement proposed by Nakata [7,8]. Because the H-coil sensor is slightly distanced from the sheet surface to improve the accuracy of magnetic field strength measurement the additional second coil was used. From the signals of both H-coils the magnetic field directly on the sheet surface can be extrapolated. This principle can be further improved by using three of four coils [9].

III. THE CHOICE OF MAGNETIC FIELD SENSOR

Assuming that for magnetic field strength determination direct measurement of magnetic field above the sheet is more reliable various methods and sensors have been compared [10]. The results of such comparison are presented in Fig. 4. The signal from magnetizing current (the voltage drop on resistor 0.2 Ω) was compared with the signal from H-coil sensor with dimensions 0.5 × 28 × 45 mm and 900 turns. This sensor exhibited sensitivity of about 7 mV/(kA/m). Additionally the AMR (thin film magnetoresistive) sensor KMZ10B of Philips with sensitivity of about 30 mV/(kA/m) was used.

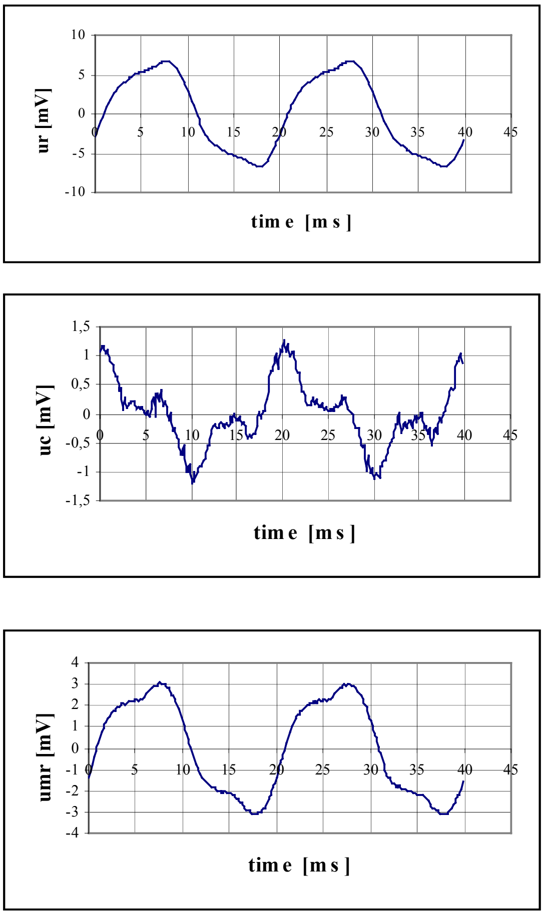

Fig.4. Comparison of the signals obtained from the magnetizing current (ur), H-coil (Uc) and MR sensor (umr) for the non-oriented steel sample magnetized to *1 T* (*H* equal to about *100 A/m*)

Fig. 4 presents the comparison of signals for non-oriented steel strip sample magnetized to flux density *1T* – the magnetic field strength was about *100 A/m*. The best quality signal was obtained from the magnetizing current. The signal of H-coil sensor was disturbed by noise. For smaller magnetic field strength values, as for example several *A/m* (typical for grain-oriented steel magnetized to *1T*) signal from the coil was comparable with noise level.

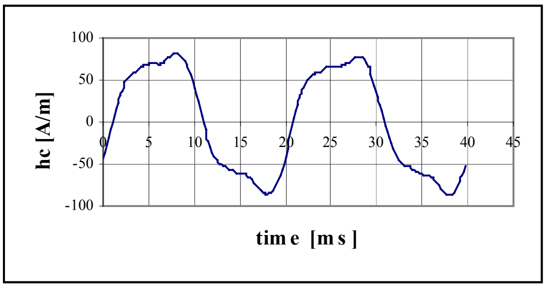

Fig.5. The signal of the H-coil sensor after integration (signal uc presented in Fig.4 after integration)

Signal of the typical coil sensor was small (less than *1 mV* for *100 A/m*) and it was not the signal representing magnetic field strength *H* but according to Faraday's law it was proportional to *dH/dt*. Thus integration of the signal was necessary. After integration the signal was improved what illustrates Fig.5.

Signal of H-coil sensor is small, noisy and requires integration. Much better performances exhibits signal from the AMR sensor (Fig. 4: signal umr). Therefore authors proposed to substitute the traditional H-coil sensor by thin film magnetoresistive sensor.

IV. AMR SENSOR FOR MEASUREMENT OF MAGNETIC FIELD STRENGT IN ELECTRICAL STEEL

Thin film magnetoresistive sensor was with success used for investigations of electrical steels [11,12]. Its advantages are as follows:

- the sensor measures the magnetic field component in the film plane, thus it is the sensor of tangential field component suitable to measure the field in the sample;
- it measures directly magnetic field strength *H* and it is not necessary to use the integrating circuit (as in the case of coil sensor);
- the sensitivity *30 mV/(kA/m)* and range *2 kA/m* of typical AMR sensor KMZ10B of Philips corresponds very well with typical range of magnetic field in electrical steel enabling to obtain sufficient signal even von several A/m in the sample.

But typical AMR sensors with dimensions of about *1 mm × 1 mm*, is not suitable for testing of the grain oriented steel samples. Such small AMR sensor was adapted to scanning system called magnetovision [12-14]. Fig.6 presents the results of scanning of magnetic field above the grain oriented steel samples.

Fig. 6 presents results of scanning of magnetic field above the samples with dimensions *6 cm × 6 cm* cut from the same steel sheet. We see that both samples differs each other with magnetic field strength value and what is important, due to the grain structure the variation of magnetic field strength is large, in some parts the magnetic field is equal to 50 A/m while in other parts is ten times larger. Thus the sensor should be larger than grain dimensions to correct measure the mean value of magnetic field strength in the sample.

Fig.7 present the magnetic field strength distribution above the sample of HiB grain oriented steel with improved texture and large grains. Also in this case the variation of magnetic field is large - from about 10 A/m to 100 A/m. By comparison of the maps presented in Figures 6 and 7 we see that the uniformity of magnetic field strength distribution can be used not only to analyze of the heterogeneity but also to analyze of the grain structure [15].

Presented results of scanning of magnetic field above the grain oriented steel samples demonstrate that to correct measure the magnetic field strength the sensor should be sufficient large - larger than about *3 cm × 3 cm*. In the case of small AMR sensors the solution is to use the multi-sensor matrix (called later the sensors array) covering such area.

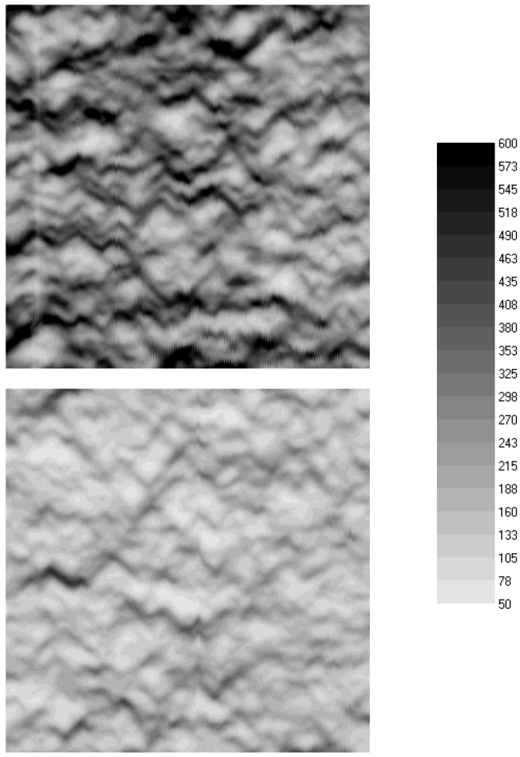

Fig.6. The results of scanning of the magnetic field above the grain-oriented steel samples magnetized to 1.7T

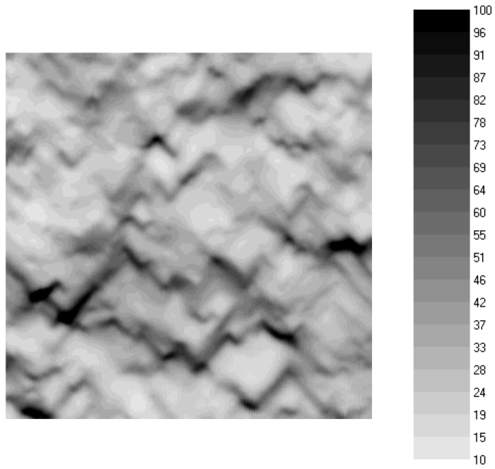

Fig.7. The magnetic field strength distribution above the HiB grain oriented steel sample magnetized to 1.7 T

V. The AMR SENSORS ARRAY

It was designed the sensors array consisted of 16 AMR KMZ10B sensors. Such sensor array can be used in two modes:

- all sensors can be serially connected and this way we obtain 16-times larger sensitivity (about 500 mV/(kA/m) and simultaneously by measurements of magnetic field in 16 points we obtain averaging effect for large area;
- it is also possible multiplexing all sensors to measure the magnetic field in 16 points. This way we can

additionally determine the uniformity of magnetic field distribution – the homogeneity of the material structure and grain structure.

The sensors array was designed and constructed. Fig. 8 presents the design of such sensors matrix. Because the sensors are in bridge circuit form output or inputs of the sensors should be galvanically separated to connect the sensors in series. In presented case the supply transformer with 16 output windings was used.

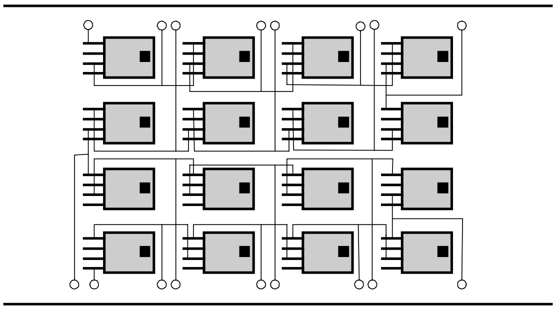

Fig.8. The sensors array designed for 3 cm width steel strip

The whole new type of Single Strip tester is presented in Fig. 9.

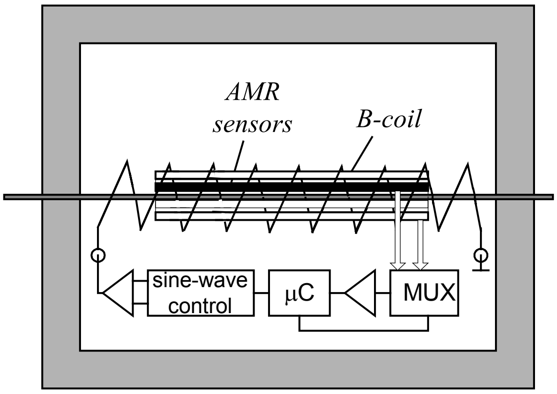

Fig. 9. The Single Strip Tester circuit with AMR sensors array

To correct operation of proposed testing device simple electronics is necessary. The microcontroller is used to control the sine wave of flux density in the sample, to calculate steel parameters (losses, permeability etc) and to perform statistical calculations. This statistical calculations helps in assessment of the material heterogeneity and grain structure.

VI. CONCLUSIONS

Presented tester of magnetic materials in form of a strip exhibits following features:

- large output signal representing magnetic field strength and proportional to tangential component of the magnetic field strength in the sample;
- it is not necessary to use the integrating amplifier (what is required in the case of coil sensors);
- possibility of analyze of the material heterogeneity and partially grain structure (what was not possible in other single strip testers).

It is possible to increase the number of sensors. But earlier analysis [16] proved that sixteen sensors is enough to obtain average value representing the whole sample and to perform correct statistical analysis of material heterogeneity.

The device was tested with data acquisition board (multiplexer and amplifier on board) and typical PC computer. But due to simplicity it is possible to design such device as low cost and portable one with several amplifiers, multiplexer and microcontroller.

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